1876MNRAS..36..300P

well suited for a first experiment, the facilities being great and the field large, while many uncertainties in the longitudes, especially on the south shore of the Caribbean Sea, where they amount to some five or six miles, need to be cleared up. In other parts of the world, however, the uncertainties are a good deal greater. It is not too much to hope that other nations will promptly follow the lead taken by the American hydrographers, and that especially our own Hydrographic Department will add this branch of work to the admirable maritime surveys in which it is justly pre-eminent. The vast and constantly spreading network of telegraphic cables and land lines will afford work for many years to come; and each extension of measurements of the class I have described will add accuracy to geographical knowledge and marine cartography.

Barbados, West Indies,
1876, *March* 20.

On the Relative Power of Achromatic and Reflecting Telescopes.

By T. R. Robinson, D.D., F.R.S., &c.

In an article which appeared in *Les Mondes*, Jan. 20, 1876, by M. Radau, on large Telescopes, he remarks, after noticing the comparison of the relative illuminating power of Achromatics and Reflectors, which I made in the description of the Great Melbourne Telescope (*Phil. Trans.* 1869), "the theoretic proportion established by Mr. Robinson between equivalent apertures of a Reflector and Refractor is not however conformable to experience, which is entirely in favour of the Refractor."

Even were it true that an Achromatic shows objects better than an equivalent Reflector, it would not contradict my theory, which merely refers to light. The theory is, in brief, that a speculum collects in its focus a quantity of light proportional to its area, and a constant depending on the reflective power of its material; the Achromatic a quantity depending on its area, and a co-efficient which contains a negative exponential function of the aperture, and of course decreases more rapidly than the area increases. Therefore, though for small apertures the light of the Achromatic exceeds that of an equal speculum, yet as the aperture increases, the disparity decreases until at a size determined by the reflective power of the speculum and the refractive indices and absorptive power of the glasses, their lights become equal; and above that the Reflector predominates. Since, therefore, both the difficulty and cost of construction increase far more rapidly with aperture in the Achromatic than in the Reflector, it is evident that as far as light is concerned, the ultimate practical limit of telescopic research can only be obtained by the latter.

Having premised so much, I proceed to consider (1) what

1876MNRAS..36..305R

reasons can exist for the superiority that is ascribed to the Achromatic, and (2) whether they *do* exist.

If one of two equiluminous telescopes shows a faint object better than the other, this can only arise from the first condensing its light into a smaller image. In this respect the Achromatic presents greater difficulties than its rival: it has two aberrations to be corrected, chromatic and spherical, of which the first is never completely destroyed,* and the second requires the careful figuring and centering of four surfaces; any defect of homogeneity in its glasses disturbs the image; defective annealing, from which scarcely any large lenses are free, tends to produce diffusion, and the same mischief may arise from strain caused by pressure on its supports.

On the other hand, a speculum has only one surface to be figured, and with the present improved processes of polishing, *that can be done with remarkable precision.* But it is very sensitive to irregular pressure. This has been greatly remedied by the systems of supporting levers invented by Grubb and Lassell, which may probably be still further improved; and I believe that by a better mechanical disposition of the material, its strength may be greatly increased. The only point in which it is decidedly inferior to the object-glass is the occurrence of convection currents when the speculum and the air differ much in temperature. Even this is greatly obviated by making the tube of lattice-work, and it would not be difficult to devise mechanical means to reduce it still further. It is also to be noticed that there are some grounds for believing that large Achromatics have their aberration correction disturbed by considerable changes of temperature.

On the whole, therefore, it may be expected that a good instrument of either class shall perform equally if equal in light; and it is certain that superior definition will compensate only to a very limited extent for deficiency of light.

But secondly, what evidence have we that "Experience is entirely in favour of the Refractor?" None that will bear examination.

1. We are told that W. Struve thought the Dorpat telescope of 9·6-inches aperture might be compared to Herschel's 20-feet of 18-inches aperture. This rested mainly on the fact, that he discovered with it the 5th star in the Trapezium of *Orion*, which was not seen by J. Herschel in his careful examination of the Great Nebula. The obvious explanation of this is, that Herschel was attending to the Nebula and nothing else. But, in fact, his telescope showed not only the 5th, but also the 6th star which was in the Dorpat. Lassell saw both in a 9-inch Newtonian; and I have myself seen the 5th with a zone of the Armagh Cassegrain,

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* It is doubtful whether the Harcourt glass, with which Mr. Stokes has recently formed an object-glass free from secondary spectrum, can be made on a large scale.

1876MNRAS..36..305R

the area of which was only 0·78 that of the Dorpat. This object is, therefore, far within the range of any of these telescopes.

2. Otto Struve *thought* that the Pulkowa Achromatic of 15-inches was equal to Lassell's 24-inch Newtonian (not his 4-feet, as supposed by M. Radau): nothing definite can be built on this. It seems only to have shown three satellites of *Uranus*, while the other (Lassell's) showed four.

3. We are told that M. D'Arrest's Achromatic of 11-inches aperture "is very superior to Herschel's 20-feet, and almost equal to the great telescope of Lord Rosse."

D'Arrest himself, though very enthusiastic about his instrument, makes no such pretensions. In his *Instrumentum Magnum* he merely says, that "he could reach with his telescope all the Herschel Nebulæ without any exception," and in the preface to his great Catalogue that "it is in no wise inferior, non ullo nomine postponendum, to the Herschel telescopes on which this part of science had been built." But seeing all these Nebulæ does not prove that the telescope was equal in power, unless all the other conditions were identical. (1.) It is far easier to see an object the existence, place, and form of which are known than to discover one that is unknown; examples of this are familiar to every one who has used a telescope. (2.) He had the great advantage of a steady Equatoreal moved by clockwork; this gives a power of minute examination, the value of which can be appreciated only by persons who have worked with telescopes mounted like those of Herschel and Rosse. (3.) Much depends on the observer's power of vision; if M. D'Arrest were as sharpsighted as, for instance, my friend the late Mr. Dawes, this would compensate for considerable deficiency of optical power. No satisfactory comparison can be made from the descriptions in catalogues; they are always incomplete. No description of a tolerably complex nebula would enable a man who had not seen it to make a drawing at all like it. D'Arrest, in his *Instrumentum Magnum* has given some figures, which show superiority to those of Herschel where they differ; and where they are also given in Lord Rosse's papers (*Phil. Trans.* 1844, 1850, 1864), Herschel is on the whole nearer to these last than D'Arrest. As to the notion that the Danish telescope "is almost equal to Lord Rosse's great one," we have only to compare D'Arrest's fig. 4, of 1 M, with Rosse's fig. 81, *Phil. Trans.* 1844, taken with the *three-feet*, to be convinced that even this lesser telescope is enormously superior to the other.

Let it also be remembered that while two of the satellites of *Uranus* were *observed* repeatedly with the 20-feet, there is no evidence that any of them were ever *seen* in an 11-inch Achromatic.

All these statements of the superior power of Achromatics are so little supported by accurate data, that it may seem a waste of time to confute them, but such baseless assertions "darken knowledge" and if accepted, impede progress. I repeat my belief that it is only by large Reflectors that we shall reach the utmost depths

1876MNRAS..36..305R

of celestial exploration in stellar spectroscopy, and the study of the remoter planets and Nebulæ; and, instead of unwisely depreciating this power, it is a wiser course to consider how their real defects may be remedied.

Of these the most serious is the liability of speculæ to tarnish, and the consequent necessity and risk of frequent repolishing. Has science no means of preventing the tarnish, which is an oxidation of the surface probably caused by the presence of moisture?

Lord Rosse and I separately tried to guard against this by connecting with the speculum box (when the instrument was not in use) a vessel containing quicklime; but I have some reason to think that as it became "slacked" it evolved something that acted on the metal.

Would it be protected by keeping it in a state of negative electric tension? Sir John Herschel told me that when his father sorrowfully showed him a 20-feet speculum, the finest he had ever made, but then become black, he delighted the old man by restoring completely its polish, having placed it in a solution of salt in contact with a piece of zinc; and afterwards it did good work.

The operation of polishing even a 6-feet, is neither so difficult or uncertain as many persons suppose. If, when the right mode of making the polisher, and the proper action of the machine, are once ascertained, they be exactly formulated, *and that formula be always carefully followed*, I venture to assert that failure will be very rare.

The late Lord Rosse—while, with that caution which was so remarkable a feature of his character (*Phil. Trans.* 1864), he rather overstates the uncertainty in the process—also says, that in every such instance something which experience had shown to be important had been forgotten or neglected. In the case of the 6-feet, the difficulty was much increased by the impossibility of testing the figure of the speculum while the polishing was proceeding: it had to be removed to the telescope half a mile distant for trial, which owing to unfavourable weather sometimes could not be made for many days; and this suspension was unfavourable, for the operation should be continuous. This, and the trouble of moving so great a mass, sometimes made him work with surfaces of second-rate quality. Towards the close of his life he contrived the means of setting the speculum vertical on the machine, so that in a few minutes it could be tested on a watch-dial. The 3-feet was from the beginning tested on the machine, and success with it was almost certain. But even with the old method I have seen results for the 6-feet that gave marvellous definition, and none that in favourable atmospheric circumstances were not capable of doing work beyond the power of any telescope which then existed. The time of actually polishing it need not exceed 6 hours; and though he never used the same polisher twice (the making of which is rather tedious) yet neither Lassell or Grubb have found this necessary for 4-feet specula. It is to be wished

1876MNRAS..36..305R

that some ready means may be found for trying the diminution of light by tarnish. I think, if the image of a lucid disk were formed beside it at the centre of curvature, the two could be photometrically compared rapidly and without moving the speculum from the tube.

As to the ultimate possible size of a speculum of metal, an accident that occurred in casting a 6-feet, at which I was present, satisfied us that one of 7-feet could be made; nor is this the limit. But if the 4-feet "Foucault" just erected at Paris prove, as I hope it will, a great success, it is probably in that direction that the improvement of very large specula will tend. It will probably be difficult to form large glass disks with sufficient uniformity of strength in every direction, to resist distortion; but on the other hand, silver is so much more reflective than speculum metal,* that its equiluminous aperture will be only $\frac{2}{3}$rds of the other.

I look to this telescope with great interest; for, from it in conjunction with the great Refractor which is now in construction for the Observatoire, can alone be expected a really accurate comparison of the Achromatic and Reflector. As I have elsewhere stated, such comparison can only be fairly made when the conditions are identical; when the locality, the night, the object, the observer are the same; and I may add, when there is no personal or party bias in the judge. An observer becomes in some cases so much attached to his instrument as almost to identify himself with its character; and it may even happen that national feeling is interested in favour of a particular artist. All will be favourable at the Observatoire, and I trust that M. Le Verrier and his accomplished assistants will profit by so auspicious an opportunity.

On the Transit across the Sun's Disk of the Second or Great Comet of 1819. By J. R. Hind, Esq.

The second or great Comet of 1819 made its appearance in these latitudes under circumstances very similar to those attending the early visibility of the great Comet of 1861. It ascended above the north-west horizon as a conspicuous naked-eye object, and was very generally detected in Europe in the first days of July. The earliest observation for position appears to have been made by Professor Tralles at Berlin on the evening of the 1st of the month, and the latest observations were made by Struve at Dorpat and by Olbers at Bremen in the middle of October.

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* The mean of Jamin's co-efficients for silver at perpendicular incidence is 0·90, which gives for the Newtonian 0·81, greater than that of most Achromatics. It is, however, doubted whether a film reflects as much as solid silver. A Committee has been appointed by the British Association to examine this, and some other cases of reflection.